5.4.1 Dam Failure

Introduction/History
Two dam failure disaster declarations (Presidential or Gubernatorial) and four additional undeclared dam failure events were identified in Arizona. Collectively, these events resulted in an estimated 150 fatalities. A sampling of these events is listed below:

- February 22, 1890, the most significant dam failure experienced in the State occurred in Walnut Grove. The dam failed due to overtopping and the ensuing flood caused an estimated 150 deaths and extensive destruction of property. The failure was blamed on inadequate capacity of the spillway and poor construction (ADEM, March 1998). Located 30 miles by river north of Wickenburg on the Hassayampa River, the dam was built to provide water for irrigation and gold placer mining. The rock fill structure was 110 feet high, 400 feet long, had a base width of 140 feet, a top width of 10 feet, and a spillway of 5 - 20 feet long. The lake was 2.5 miles long by one mile wide covering over 1,100 acres, and an average depth of 60 feet. Based upon various accounts of the Walnut Grove Dam failure, the weather at the time was rain and melting snow. The day before the breach, water in the lake rose rapidly at the rate of about one and one-half foot per hour. The spillway was enlarged to allow excess water to escape but the effort was insufficient to stop water from running over the top. A sheet of water three feet thick reportedly poured over the dam top for six hours. Between 1:00 - 2:00 am on February 22, 1890 the dam broke and the lake drained in one to two hours. The water rushed down Box Canyon, a narrow, steep canyon in a body 80 feet high. Floodwaters reached the Wickenburg, 30 miles downstream in two hours and was reportedly still in a column 40 feet high.
- September 1997, Centennial Narrows Dam in Maricopa County failed due to flooding from Hurricane Nora. This failure is significant because the single-purpose flood control dam most likely failed due to flow through transverse cracks through the dam. Major population areas in Maricopa and Pinal Counties are protected by earthen dams experiencing similar cracking.
- October 22, 1997, a mine tailings dam owned by BHP Copper failed due to slope failure. Approximately 300,828 cubic yards of tailings and mine rock tailings were released.
- April 19, 2004, a State Declaration of Emergency was declared at River Reservoir No. 3 Dam in Apache County due to concern based on observed seepage and internal erosion. The large volume of seepage and eroded embankment soil was first observed on March 30, 2004. Successively larger increases in seepage flow and eroded embankment soils reached a magnitude on April 13 that appeared to indicate an imminent failure was possible. The County Sheriff mobilized personnel to monitor the dam on a 24-hour basis to provide early warning of a dam failure and to facilitate evacuation of residents in the threatened downstream communities of South Fork, Eagar and Springerville. The reservoir was drained and the dam repaired the following year.

Arizona's Dam Safety Program has existed since 1929. Prior to 1971, funding for the Program was minimal and sporadic. Legislative approval of a consistent budget since 1971 has authorized permanent staffing and the development of a comprehensive Dam Safety Program. Arizona dam safety law includes the major areas suggested by the National Dam Safety Program Act and the United States Committee on Large Dams. The Arizona Revised Statutes (A.R.S.) § 45-1201 assigns the responsibility for supervision of the safety of non-federal dams to the Director of the Arizona Department of Water Resources (ADWR). The mission of the ADWR Dam Safety Section is to maximize the protection of the public against loss of life and property by reducing the likelihood of catastrophic failure of dams within the state's jurisdiction.

A.R.S. § 45-1201 defines a jurisdictional dam as an artificial barrier for the impounding or diversion of water either 25 feet or more in height or having a storage capacity of more than 50 acre-feet, but does not include:

- Any barrier for the purpose of storing liquid-borne material (e.g. mine tailings dams),
- Any barrier that is a "release-contained barrier,"
- Any barrier that is federally owned and operated, and
- Sole use transportation structures

The statutes further define "height" as the vertical distance from the lowest elevation of the outside limit of the barrier at its intersection with the natural ground surface to the spillway crest elevation. "Storage capacity" is defined as the maximum volume of water, sediment, or debris that can be impounded in the reservoir with no discharge of water, including the situation where an uncontrolled outlet becomes plugged.

In order for an artificial barrier and/or appurtenant works structure to be considered a "release-contained barrier," both of the following criteria should comply:

a) Has storage capacity that in the event of failure would be contained within property that the release-contained barrier owner owns, controls, operates, maintains or manages.

b) The property on which the release would be contained is not open to the public.

Map 18
Map 18 illustrates the locations of all state jurisdictional dams and federal dams. Data was obtained from ADWR and the National Inventory of Dams (NID).

Potential Secondary/Cascading Effects
The most obvious secondary effect of a dam failure is flooding and the associated damages due to erosion, debris, and hazmat contamination. Another secondary impact would be the loss of stored water and that impact during a season of drought. This would be especially true if the reservoir were relied upon as a source for irrigation or drinking water. Ground fissures located in the downstream floodpath could also be enlarged with the flowing water. A dam failure could also trigger a mudslide in the right conditions depending on the geology of the area, and especially in the rapidly evacuated pool area.

Probability and Magnitude
A dam failure is an uncontrolled release of water impounded behind the dam. Dam failures may occur due to a variety of causes. As shown in the table below, the three most common causes, i.e. leakage and piping, overtopping, and spillway erosion have been responsible for 74% of historic failures.

Causes of Dam Incidents (Dam > 50 Feet High)	
Fundamental Causes	**Percentage**
Foundation Leakage & Piping	35
Overtopping	25
Spillway Erosion	14
Excessive Deformation	11
Sliding	10
Gate Failure	2
Faulty Construction	2
Earthquake Instability	2
Source: "Safety of Existing Dams, 1983, National Research Council	

Jurisdictional dams in Arizona can generally be divided into two groups: (1) storage reservoirs designed to permanently impound water, and (2) normally dry single-purpose flood control structures designed to impound water for short duration of times during flood events. In Arizona, storage reservoirs are common in the higher elevations of the state while single-purpose flood control dams are prevalent in the lower elevations.

Primary Dam Failure Risks on "Sunny Days" and During Flood Events		
	"Sunny Day"	Flood Event
Storage Reservoir Dams	Leakage and Piping	Leakage & Piping, Overtopping, Spillway Erosion
Single-Purpose Flood Control Dams	Not Applicable	Leakage & Piping, Overtopping, Spillway Erosion

Typically, the dam-break floodplain is more extensive than the regulatory floodplains used for land use development purposes and few communities consider upstream dams when permitting development. The potential severity of a full or partial dam failure is influenced by several factors: the amount of water impounded, the rate of failure; and the density, type, and value of development and infrastructure downstream.

The following two information sources provide an indication of the risk posed by specific dams in Arizona and the potential for their failure:

- Arizona Department of Water Resources (ADWR) Dam Safety Program: ADWR has jurisdiction of 250 dams in Arizona. From this total, approximately 230 dams are earthen structures, 5 dams are arch, 5 are masonry, 5 are concrete gravity, 1 is a roller compacted concrete, and 4 are considered other types of structures. The average height and storage capacity are approximately 32 feet and 2,000 acre-feet. Major program areas include: applications to construct, modify or remove; construction monitoring; inspection and oversight of existing dams; EAP planning and response; unsafe dam rehabilitation; and unregistered (violation) dams. A Dam Safety Database was created to store information on the physical attributes of the dam as well as ownership, location, hazard rating, safety types and deficiencies, and EAPs.
- National Inventory of Dams (NID): The NID contains information on approximately 79,000 dams throughout the United States that meet the following criteria: it is a high or significant hazard potential class dam or, it is a low hard potential class dam that exceeds 25 feet in height and 15 acre-feet storage, or it is a low hazard potential class dam that exceeds 50 acre-feet storage and 6 feet in height. The NID is maintained, updated, and published by the U.S. Army Corps of Engineers with information from all 50 states, Puerto Rico, and 16 Federal agencies. The inventory consists of 54 data fields that describe the physical and regulatory aspects of the dam, including name, owner, river, nearest city, length, height, average storage, hazard rating, EAP, and location. In 2006, the NID database listed 328 dams that were located in the State of Arizona.

The NID and ADWR databases provide useful information on the potential hazard posed by dams. Each dam in the NID is assigned one of the following three hazard potential classes based on the potential for loss of life and damage to property should the dam fail (listed in increasing severity): low, significant, or high. The hazard potential classification is based on an evaluation of the probable present and future incremental adverse consequences that would result from the release of water or stored contents due to failure or improper operation of the dam or appurtenances, regardless of the condition of the dam. The ADWR evaluation includes land-use zoning and development projected for the affected area over the 10-year period following the classification of the dam. It is important to note that the hazard potential classification is an assessment of the consequences of failure, but not an evaluation of the probability of failure or improper operation.

Downstream Hazard Potential Classes for State Regulated Dams		
Hazard Potential Classification	**Loss of Human Life**	**Economic, Environmental, Lifeline Losses**
Low	None expected	Low and generally limited to owner
Significant	None expected	Yes
High	Probable. One or more expected.	Yes (but not necessary for this classification)

Note: The hazard potential classification is an assessment of the consequences of failure, but not an evaluation of the probability of failure. Sources: NID, ADWR

Identified Federal and State Regulated Dams in Arizona, 2009				
County	**High Hazard Potential**	**Significant Hazard Potential**	**Low Hazard Potential**	**Total**
Apache	15	8	39	62
Cochise	3	3	10	16
Coconino	10	5	30	45
Gila	3	3	1	7
Graham	21	3	21	45
Greenlee	1	1	14	16
La Paz	1	1	2	4
Maricopa	44	6	7	57
Mohave	3	3	11	17
Navajo	12	5	38	55
Pima	4	3	5	12
Pinal	10	5	6	21
Santa Cruz	2	0	2	4
Yavapai	7	4	28	39
Yuma	3	1	3	7
Total	**139**	**51**	**217**	**407**

Source: NID, ADWR Dam Safety Database (October 2009)

Federal Dams on the Salt/Verde River, the Aqua Fria River, the Gila River, and the Colorado River pose a potential threat to population centers and agricultural lands within the State (refer to the following table). For example, failure of any U.S. Bureau of Reclamation dams on the Salt/Verde River or the Aqua Fria River would cause massive flooding in Phoenix and Maricopa County. Failure of Coolidge Dam, a Bureau of Indian Affairs Dam, on the Gila River could cause massive flooding in the Winkelman and Hayden areas of Gila County; Kearny, Florence and the Gila River Indian Reservation in Pinal County; and possibly portions of Maricopa County. Failure of Painted Rock Dam, an Army Corps of Engineers dam, also on the Gila River system, could result in massive flooding of portions of Maricopa and Yuma Counties, including the City of Yuma. Failure of any or all the Bureau of Reclamation dams on the Colorado River would cause massive flooding in Mohave, La Paz and Yuma Counties.

High and Significant Hazard Potential Federal Dams Located on Major Arizona Rivers							
River	NID	Dam Name	Hazard Class	Height (ft.)	Storage (ac-ft.)	Purposes	Nearest Downstream Development
Salt	AZ10317	Theodore Roosevelt	High	357	3,432,408	Irrigation, Hydroelectric, Recreation	Globe
	AZ10311	Horse Mesa	High	305	261,335	Irrigation, Hydroelectric, Water Supply	Mesa
	AZ10313	Mormon Flat	High	224	57,852	Irrigation, Hydroelectric, Water Supply	Mesa
	AZ10318	Stewart Mountain	High	207	70,070	Irrigation, Water Supply, Hydroelectric	Mesa
Verde	AZ10308	Bartlett	High	309	249,693	Water Supply	Mesa
	AZ10310	Horseshoe	High	202	214,372	Water Supply, Irrigation	Fort McDowell
Agua Fria	AZ82929	New Waddell	High	438	1,063,163	Recreation	Peoria
Gila	AZ10436	Coolidge	High	252	1,073,000	Irrigation, Hydroelectric, Recreation	Winkelman
	AZ10002	Painted Rock	High	181	4,831,500	Flood Control & Storm Mgmt	Agua Caliente
Colorado	AZ10307	Glen Canyon	High	710	29,875,000	Hydroelectric, Irrigation, Recreation, Other	Lees Ferry
	NV10122	Hoover	High	730	29,755,000	Hydroelectric	Bullhead City
	AZ10312	Parker	High	320	180,000	Water Supply, Irrigation, Hydroelectric	Parker
	AZ10309	Davis	High	200	1,592,300	Hydroelectric	Bullhead City
	CA10159	Imperial	No Data	No Data	No Data	Irrigation	Yuma
	AZ10437	Headgate Rock	Significant	34	20,000	Irrigation, Hydroelectric	Parker
Bill Williams	AZ82203	Alamo	High	283	1,409,000	Flood Control	Parker
Sources: NID, ADWR							

State regulated single-purpose flood control dams operated and maintained by the Flood Control District of Maricopa County provide flood protection to large populations in the Phoenix Metropolitan Area. Failure of any of these dams would cause serious flooding.

State regulated dams are inspected regularly by ADWR according to downstream hazard potential classification. High hazard dams are inspected annually; significant hazard dams, every three years; and low hazard dams every five years. During inspections, "safety deficiencies" are sometimes identified and the owners are required to implement corrective actions. A "safety deficiency" refers to a condition at a dam

that impairs or adversely affects the safe operation of the dam, per the A.A.C. R12-15-1202. Such conditions may include embankment cracks, erosion, breaching, unusual/uncontrolled seepage, slope instability and/or inadequate spillway capacity. Following each safety inspection, a written report is returned to the owner identifying the safety deficiencies and making recommendations for needed maintenance work. ADWR tracks the safety deficiencies and works to assist dam owners in their resolution. Safety deficiencies which left uncorrected could result in dam failure with subsequent loss of human life or significant property damage will classify the dam as "Unsafe," per A.A.C. R12-15-1202. The following tables provide the safety rating definitions and the number of state regulated dams classified as having a safety deficiency or considered unsafe.

State Regulated Dam Safety Ratings	
Safety Rating	**Definition**
No Deficiency	Not Applicable
Safety Deficiency	One or more conditions at the dam that impair or adversely affects the safe operation of the dam.
Unsafe Categories	
Category 1: Unsafe Dams with Elevated Risk of Failure	These dams have confirmed safety deficiencies for which there is concern they could fail during a 100-year or smaller flood event. There is an urgent need to repair or remove these dams.
Category 2: Unsafe Dams Requiring Rehabilitation or Removal	These dams have confirmed safety deficiencies and require either repair or removal. These dams are prioritized for repair or removal behind the Category 1 dams.
Category 3: Unsafe Dams with Uncertain Stability during Extreme Events (Requiring Study)	Concrete or masonry dams that have been reclassified to high hazard potential because of downstream development (i.e. hazard creep"). The necessary documentation demonstrating that the dams meet or exceed standard stability criteria for high hazard dams during extreme overtopping and seismic events is lacking. The dams are classified as unsafe pending the results of required studies. Upon completion of these studies, the dams are either removed from the list of unsafe dams or moved to Category 2 and prioritized for repair or removal.
Category 4: Unsafe Dams Pending Evaluation of Flood-Passing Capacity (Requiring Study)	In 1979, the U.S. Army Corps of Engineers established Federal Guidelines for assessing the safe-flood passing capacity of high hazard potential dams (CFR 44 No. 188). These guidelines established one-half of the "probable maximum flood" (PMF) as the minimum storm which must be safely passed without overtopping and subsequent failure of the dam. Dams unable to safely pass a storm of this size were classified as being in an "unsafe, non-emergency" condition. Prior studies for these earthen dams (mostly performed in the 1980's) predicted they could not safely pass one-half of the PMF. They were predicted to overtop and fail for flood events ranging from 30-46% of the PMF. Recent studies both statewide and nationwide have indicated that the science of PMF hydrology as practiced in the 1990's commonly overestimates the PMF for a given watershed. The ADWR is leading efforts on a statewide update of probably maximum precipitation (PMP) study scheduled for completion in 2011. These dams should be re-evaluated using updated methods to confirm their safety status. Upon completion of these evaluations, they are either removed from the list of unsafe dams or moved to Category 2 and prioritized for repair or removal.

Map 19
Map 19 shows all of the state regulated dams that are classified as unsafe or have safety deficiencies associated with them. Data was obtained from ADWR Dam Safety Database.

State Regulated Dams with Identified Safety Deficiencies, 2009					
County	Safety Deficiency	Unsafe Dams with Elevated Risk of Failure	Unsafe Dams Requiring Rehabilitation or Removal	Unsafe Dams with Uncertain Stability during Extreme Events (Requiring Study)	Unsafe Dams Pending Evaluation of Flood-Passing Capacity (Requiring Study)
Apache	1	0	1	0	0
Cochise	1	0	0	0	0
Coconino	3	1	1	1	0
Gila	0	0	0	0	0
Graham	5	1	0	1	4
Greenlee	1	0	0	0	0
La Paz	0	0	0	0	0
Maricopa	8	0	2	0	0
Mohave	2	0	0	0	0
Navajo	4	0	3	0	2
Pima	4	0	0	0	0
Pinal	0	1	1	0	0
Santa Cruz	0	0	0	0	0
Yavapai	4	0	0	0	0
Yuma	0	0	0	0	0
Total	**33**	**3**	**8**	**2**	**6**
Source: ADWR Dam Safety Database (October 2009)					

ADWR requires each owner of a high and significant hazard potential state regulated dam to prepare, maintain, and exercise a written emergency action plan (EAP) for immediate defensive action to prevent failure of the dam and to minimize any threat to downstream development, per A.A.C. R12-15-1221. The EAP defines the dam owner's requirements to observe his dam for emergency conditions, the responsibilities for notifying a pre-determined list of emergency responders, and a description of the downstream areas potentially affected. The EAP is required to contain the following items:

- Notification Chart
- Reservoir & Dam Description
- Delineation of Unsafe Conditions, Procedures, & Triggering Events
- Delineation of Responsibilities
- Discussion of Emergency Supplies/Equipment
- Identification of Potentially At-Risk Areas Downstream

Each owner of a state regulated dam is required to review and update the emergency action plan annually or more frequently to incorporate changes such as new personnel, changing roles of emergency agencies, emergency response resources, conditions of the dam, and information learned from mock exercises.

The next table provides EAP status for each of the high and significant hazard potential dams within each county. Data was obtained from the ADWR Dam Safety Database.

Emergency Action Plan Status for State Regulated Dams, 2009

County	Hazard Potential Classification	Dams within hazard Potential Classification	Dams with EAPs	Dams with a Draft EAP	Dams with Outdated EAPs	Dams without EAPs	Dams with Inundation Mapping of At-Risk Areas Downstream (incl updated)	Dams without Inundation Mapping	Dams with Draft Inundation Mapping
Apache	High	3	1	0	2	0	3	0	0
	Significant	6	5	0	1	0	4	2	0
Cochise	High	3	2	0	0	1	1	2	0
	Significant	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Coconino	High	9	5	1	1	2	7	2	0
	Significant	3	1	2	0	0	1	2	0
Gila	High	1	1	0	0	0	1	0	0
	Significant	3	3	0	0	0	3	0	0
Graham	High	18	14	2	1	1	17	0	1
	Significant	3	2	0	1	0	2	1	0
Greenlee	High	1	1	0	0	0	1	0	0
	Significant	1	1	0	0	0	1	0	0
La Paz	High	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Significant	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Maricopa	High	33	32	0	1	0	33	0	0
	Significant	6	5	0	0	1	5	1	0
Mohave	High	1	1	0	0	0	1	0	0
	Significant	3	2	0	0	1	1	2	0
Navajo	High	10	6	1	3	0	7	2	1
	Significant	5	3	0	0	2	3	2	0
Pima	High	4	3	0	0	1	3	1	0
	Significant	2	0	0	2	0	2	0	0
Pinal	High	7	7	0	0	0	7	0	0
	Significant	2	2	0	0	0	2	0	0
Santa Cruz	High	2	2	0	0	0	2	0	0
	Significant	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Yavapai	High	7	7	0	0	0	6	1	0
	Significant	2	1	0	0	1	1	1	0
Yuma	High	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Significant	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Source: ADWR Dam Safety Database (October 2009)

Map 20

Map 20 shows the EAP status of all of the federal and state regulated high and significant hazard potential dams. Data was obtained from the NID and ADWR Dam Safety Databases. The tables located in Appendix D of this Plan provide the dam name, associated EAP information, and nearest downstream development for both federal and state regulated dams located in Arizona. Data sources used to develop the tables are

from the NID and ADWR Dam Safety Databases. Federal dams do not have State Inventory Database (SID) numbers and ADWR Safety Types and therefore are denoted as not applicable (N/A).

Vulnerability

The CPRI evaluation concluded that in Arizona, the future probability of occurrence for dam failure is possible, the magnitude/severity is typically critical, the warning time is less than 6 hours and the duration is less than a 6 hours. These factors resulted in a CPRI rating of 2.50 out of a possible 4.00.

The estimation of potential exposure due to a dam failure was accomplished by intersecting the human and facility assets with the inundation limits of a perceived dam failure scenario. Where available, dam failure inundation limits were obtained for dams within the state and digitized into a GIS shapefile. Sources for the inundation limits included ADWR, various county flood control districts, Bureau of Indian Affairs, US Army Corps of Engineers, and the US Bureau of Reclamation. It is noted that there are many dams within the ADWR and NID database that do not have readily available dam failure inundation mapping and none were estimated for these structures with this vulnerability analysis.

Since no common methodology is available for estimating losses from the exposure values, estimates of the loss-to-exposure ratios were assumed based on the perceived potential for damage and comparative damages to regular flooding events. Any storm event or series of storm events of sufficient magnitude to cause an emergency spillway to operate or cause a dambreak scenario, would have catastrophic consequences in the downstream inundation area. Floodwaves from these types of events generally travel very fast and possess tremendous destructive energy. Accordingly, an average loss-to-exposure ratio for the dam failure inundation areas is estimated at 50%.

In summary, $630.4 million in asset related losses to potentially impacted state-owned critical and non-critical facilities are estimated for a dam failure/inundation event. Regarding human vulnerability, a total population of 990,457 people, or 19.3% of the total 2000 state population, is potentially exposed to a dam failure or emergency spillway inundation event. The potential for deaths and injuries are directly related to the warning time and type of event. Dam failures are usually very sudden and very destructive. Given the proximities of the dams to the impacted populations, it is anticipated that moderate warning times of 2 to 3 hours are expected. However, the magnitude of such an event may realistically result in at least one death and/or several injuries. There is also a high probability of population displacement for most of the inhabitants within the inundation limits downstream of a dam.

The compilation of risk assessment data from local plans indicates that approximately $17.8 billion in locally identified critical and non-critical facilities are exposed to a "high" dam failure inundation hazard, with approximately $5 billion in potential losses estimated.

The risk assessment data tables for inundation due to dam failure are provided below.

Summary of state-owned asset inventory loss estimates based on dam failure

Jurisdictional Location	Total No. of Facilities In Jurisdiction	Percentage of State-Wide Total	Estimated Replacement Cost x $1,000)	Estimated Structure Loss (x $1,000)
Statewide	**1106**	**100.00%**	**$2,521,744**	**$630,436**
Apache	129	11.66%	$436,430	$109,107
Cochise	152	13.74%	$1,122,293	$280,573
Coconino	0	0.00%	$0	$0
Gila	69	6.24%	$95,943	$23,986
Graham	123	11.12%	$5,359	$1,340
Greenlee	0	0.00%	$0	$0
La Paz	16	1.45%	$1,747	$437
Maricopa	331	29.93%	$618,352	$154,588
Mohave	0	0.00%	$0	$0
Navajo	50	4.52%	$87,192	$21,798
Pima	146	13.20%	$112,233	$28,058
Pinal	14	1.27%	$21,322	$5,330

Summary of state-owned asset inventory loss estimates based on dam failure				
Jurisdictional Location	Total No. of Facilities In Jurisdiction	Percentage of State-Wide Total	Estimated Replacement Cost x $1,000)	Estimated Structure Loss (x $1,000)
Santa Cruz	0	0.00%	$0	$0
Yavapai	1	0.09%	$0	$0
Yuma	75	6.78%	$20,874	$5,218

State facilities located in the dam failure "high" hazard area by jurisdiction													
	Critical Facilities								Non-Critical Facilities				
Jurisdiction	Banking and Finance Institutions	Communications Infrastructure	Electrical Power Systems	Emergency Services	Gas and Oil Facilities	Government Services	Transportation Networks	Water Supply Systems	Businesses	Cultural	Educational	Recreational / Leisure	Residential
Phoenix	0	3	3	7	7	323	4	3	0	2	12	3	8
Florence	0	1	1	9	2	187	0	5	0	2	4	1	48
Tempe	0	1	0	3	0	20	6	0	2	2	126	7	62
Mesa	1	0	0	6	1	47	0	1	5	0	6	4	11
Yuma	0	0	0	0	0	6	5	1	0	18	0	0	0
Chandler	0	0	0	0	0	9	0	0	0	0	0	0	0
Safford	0	0	0	0	0	0	0	0	0	0	8	0	0
Buckeye	0	0	0	0	0	4	0	0	0	0	0	0	1
Coolidge	0	0	0	0	0	3	0	0	0	0	0	0	0
Parker	0	0	0	0	0	0	3	0	0	0	0	0	0
Lake Havasu City	0	0	0	0	0	2	0	0	0	0	0	0	0

County population sectors exposed to dam failure						
	Population					
Community	Total	Exposed	Exposed	Over 65	Over 65 Exposed	Over 65 Exposed
HIGH						
Statewide	**5,130,632**	**990,457**	**19.30%**	**665,593**	**77,728**	**11.68%**
Apache	69,426	0	0.00%	5,297	0	0.00%
Cochise	117,763	0	0.00%	17,065	0	0.00%
Coconino	116,347	2,365	2.03%	7,670	256	3.34%
Gila	51,322	528	1.03%	10,222	81	0.79%
Graham	33,499	15,031	44.87%	3,886	2,317	59.62%
Greenlee	8,546	0	0.00%	812	0	0.00%
La Paz	19,718	6,738	34.17%	5,074	1,059	20.87%
Maricopa	3,072,045	831,314	27.06%	359,065	58,368	16.26%
Mohave	155,033	30,298	19.54%	31,381	5,463	17.41%
Navajo	97,468	0	0.00%	9,173	0	0.00%
Pima	843,747	0	0.00%	119,814	0	0.00%
Pinal	179,825	34,945	19.43%	29,060	2,869	9.87%
Santa Cruz	38,376	0	0.00%	4,051	0	0.00%
Yavapai	167,491	0	0.00%	36,602	0	0.00%
Yuma	160,026	69,237	43.27%	26,421	7,314	27.68%

Summary of local risk assessment & loss estimates based on dam failure			
	Total Estimated Asset Value (x $1,000)	**Asset Value Exposed to Hazard (x $1,000)**	**Estimated Potential Losses (x $,1000)**
Statewide	**$382,041,435**	**$17,852,981**	**$4,977,430**
Apache	$11,101,665	No Data	No Data
Cochise	$10,615,770	No Data	No Data
Coconino	$22,517,439	$225,711	$56,428
Gila	$6,811,526	No Data	No Data
Graham	$2,999,628	$1,610,788	$520,497
Greenlee	$6,747,353	$36,314	$15,293
La Paz	$2,359,292	$515,342	$128,835
Maricopa	$189,975,238	$8,735,833	$2,183,958
Mohave	$15,521,558	$2,564,781	$641,195
Navajo	$11,908,834	$1,881,548	$860,558
Pima	$50,584,821	No Data	No Data
Pinal	$14,610,551	$2,282,664	$570,666
Santa Cruz	$3,044,947	No Data	No Data
Yavapai	$18,491,858	No Data	No Data
Yuma	$14,750,955	No Data	No Data
NOTE: *"No Data"* denotes lack of available information for assessment.			

Ranking of vulnerable communities to dam failure hazard										
County	**Juris**	**Total Est Losses (x $1,000) (Column 1)**	**% of Total Value (Column 2)**	**Total Population Exposed (Column 3)**	**% of Total Population (Column 4)**	**Col 1 Rank**	**Col 2 Rank**	**Col 3 Rank**	**Col 4 Rank**	**Rank Sum**
Graham	Safford	$306,751	29.4%	8,961	96.1%	3	8	4	1	16
Maricopa	Gilbert	$1,749,665	18.9%	44,383	80.8%	1	12	1	5	19
Pinal	Florence	$181,174	21.9%	16,118	92.2%	5	11	3	2	21
Graham	Thatcher	$158,691	32.5%	3,711	92.0%	7	5	7	3	22
Mohave	Bullhead City	$403,617	14.1%	21,677	64.4%	2	14	2	7	25
Navajo	Snowflake	$304,222	50.4%	1,530	34.6%	4	2	10	9	25
Pinal	Maricopa	$64,722	22.7%	1,454	77.6%	9	10	11	6	36
Pinal	Kearny	$39,824	16.3%	2,079	86.9%	11	13	9	4	37
Navajo	Taylor	$24,906	33.2%	977	30.7%	13	4	13	11	41
Pinal	Coolidge	$55,206	6.8%	2,865	32.5%	10	15	8	10	43
Maricopa	Chandler	$154,924	1.5%	5,980	6.9%	8	18	5	12	43
Maricopa	Mesa	$168,886	0.8%	4,484	2.4%	6	19	6	15	46
Greenlee	Clifton	$15,293	42.1%	115	4.5%	15	3	16	13	47
Navajo	Show Low	$24,017	31.4%	237	3.1%	14	6	15	14	49

Mohave	Colorado City	$6,587	6.6%	1,244	37.6%	16	16	12	8	52
Navajo	Pinetop-Lakeside	$3,648	29.7%	76	2.1%	18	7	17	16	58
Navajo	Winslow	$1,823	63.9%	2	0.0%	21	1	20	20	62
Mohave	Lake Havasu City	$37,328	0.6%	515	1.2%	12	20	14	18	64
La Paz	Parker	$163	25.0%	0	0.0%	22	9	22	22	75
Maricopa	Queen Creek	$2,328	0.6%	41	1.4%	20	21	18	17	76
Pinal	Apache Junction	$4,644	0.2%	10	0.0%	17	22	19	19	77
Maricopa	Gila Bend	$3,000	3.2%	0	0.0%	19	17	23	23	82

Environmental Risk & Vulnerability

Based on the *Index Values* and *Assigned Weighting Factors* determined in the table below, the CPRIs for impacts resulting from dam failure to the primary environmental components are:

Air = .85 - Water = 2.95 - Soil = 2.65 (Max CPRI for each component is 3.4)

The overall CPRI for impacts to the environment resulting from dam failure is: 6.45 (Max overall is 10.2)

CPRI Category	Degree of Risk to Arizona's AIR as a Result of Dam Failure			Assigned Weighting Factor
	Level ID	Description	Index Value	
Probability of Impact	Unlikely	Extremely rare. No documented history of occurrences/events.	1	45%
	Possibly	Rare occurrences with at least one documented or anecdotal historic event.	2	
	Likely	Occasional occurrences with 2+ documented historic events.	3	
	Highly Likely	Frequent events with a well documented history of occurrence.	4	
	Include the above Index Value & Assigned Weighting Factor in each category calculations below.			
Magnitude/ Severity	Negligible	Negligible impact.	1	30%
	Limited	Moderate impact. Special population groups may experience effects. Unlikely to impact general public.	2	
	Critical	Significant impact. General public likely to experience effects. Caution required.	3	
	Catastrophic	Severe impact. Unsafe for general public. Evacuation required.	4	
Duration of Impact/Dam age	< 1 mo	Self explanatory.	1	10%
	1 – 3 mos	Self explanatory.	2	
	3 – 6 mos	Self explanatory.	3	
	6 mos +	Self explanatory.	4	
CPRI Category	**Degree of Risk to Arizona's WATER as a Result of Dam Failure**			**Assigned Weighting Factor**
	Level ID	**Description**	**Index Value**	
Magnitude/ Severity	Negligible	Negligible impact/disruption.	1	30%
	Limited	Minor impact/disruption. No threat to public, caution limited. Possible remediation required.	2	
	Critical	Moderate impact/disruption. Consumption may require special handling/preparation actions. Remediation likely.	3	
	Catastrophic	Severe impact/disruption. Not safe for consumption/agricultural uses. Remediation required.	4	

Duration of Impact/Damage	< 1 mo	Self explanatory.	1	10%
	1 – 3 mos	Self explanatory.	2	
	3 – 6 mos	Self explanatory.	3	
	6 mos +	Self explanatory.	4	
CPRI Category	**Degree of Risk to Arizona's SOIL as a Result of Dam Failure**			**Assigned Weighting Factor**
	Level ID	**Description**	**Index Value**	
Magnitude/ Severity	Negligible	Negligible impact/disruption.	1	30%
	Limited	Moderate impact/disruption. No remediation required.	2	
	Critical	Significant impact/disruption. Recovery likely with remediation.	3	
	Catastrophic	Severe impact/disruption, rendered non-productive/unusable for agriculture and/or development for extended period of time or indefinitely.	4	
Duration of Impact/Damage	< 1 mo	Self explanatory.	1	10%
	1 – 3 mos	Self explanatory.	2	
	3 – 6 mos	Self explanatory.	3	
	6 ms +	Self explanatory.	4	

Consequences / Impacts

- **Public**
  See the "County Population Sectors Exposed to Dam Failure" in this section.
  Because dam failures can happen very suddenly, the typical impact to the general public is injuries and loss of life. Fatalities as a result of dam failure are usually due to drowning. Another very disruptive effect is when this hazard leads to isolation or evacuation. The evacuation alone can cause great trauma and stress for those affected, not to mention those who must find shelter for their pets and livestock.
- **Responders to the Incident**
  Much like the dangers of flooding, dam failure incident responders may experience injury due to debris, drowning, electrocution, cold stress and exposure to hazardous materials. Because flooded disaster sites are unstable, clean-up workers might also encounter sharp jagged debris, biological hazards in the flood water, exposed electrical lines, blood or other body fluids, and animal and human remains. Responders are prone to basically the same dangers the general public is, only on a higher level as they may be putting themselves in harm's way by performing rescue activities.
- **Continuity of Operations / Delivery of Services**
  As the table in this section titled "Ranking of Most Vulnerable Communities – Dam Inundation" illustrates, the majority of the most vulnerable communities are in Maricopa County. Maricopa County is home to the State Capitol and the main state agency buildings. The agencies housed in these buildings will be critical to the continuation of operations and services during a dam failure event in Arizona.
  Again, because dam failure leads to flooding and flash flooding, refer to the Flooding/Flash Flooding profile in this section.
- **Environment**
  Dam failure leads to flooding/flash flooding, refer to the Flooding/Flash Flooding profile in this section.
- **Economic / Financial Condition of Jurisdiction**
  Dam failure leads to flooding/flash flooding, refer to the Flooding/Flash Flooding profile in this section.
- **Public Confidence in Jurisdiction's Governance**
  Dam failure leads to flooding/flash flooding, refer to the Flooding/Flash Flooding profile in this section.

Resources

Definitions

ADWR – Arizona Department of Water Resources
EAP – Emergency Action Plan
NID – National Inventory of Dams

Sources
AZ Dept of Water Resources:
National Inventory of Dams

References
ADWR, March 2001. *Arizona's Program for Safety of Dams.*
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ADWR, July 2005. *Arizona's Dam Safety Program.*
http://www.azwater.gov/dwr/Content/Find_by_Program/Dam_Safety_and_Flood_Mitigation/Dam_Safety_Docs/Arizona_Dam_Safety_Program.pdf

Graham, Wayne. *Dam Failure Inundations – Are They Accurate?*

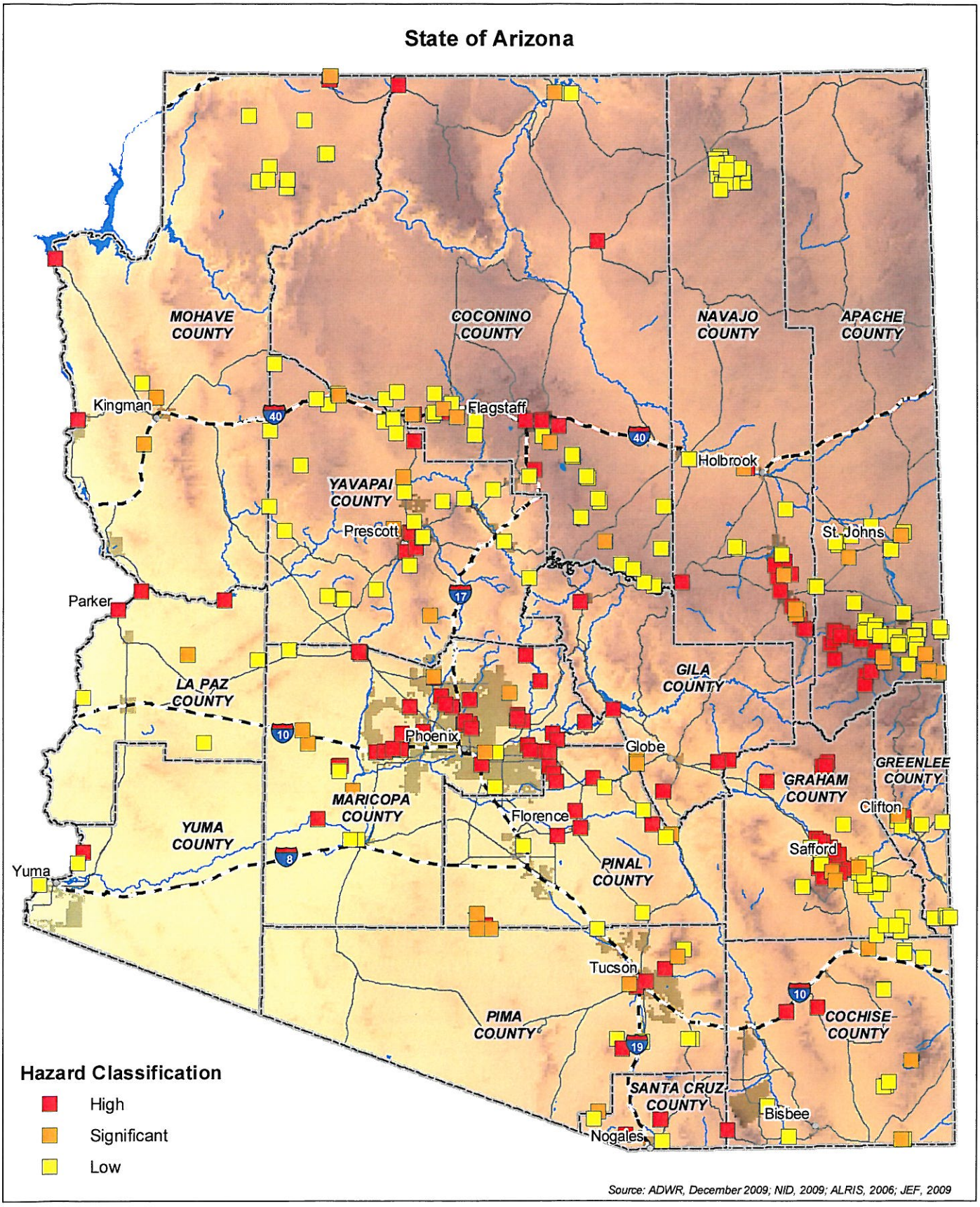
Klochko, Kateryna. *Chronology of major tailings dam failures (1970-2000),*
http://www.personal.ceu.hu/students/99/Kateryna_Klochko/Chrono.htm

Maps

Map 18 – State Jurisdictional and Federal Dam Location Map

Map 19 – State Regulated Dams With Unsafe or Safety Deficient Classifications

Map 20 – EAP Status of All Federal and State Regulated High and Significant Hazard Potential Dams



Legend

- Major City
- interstate
- Highway
- Major Streams
- County
- Lakes
- Cities

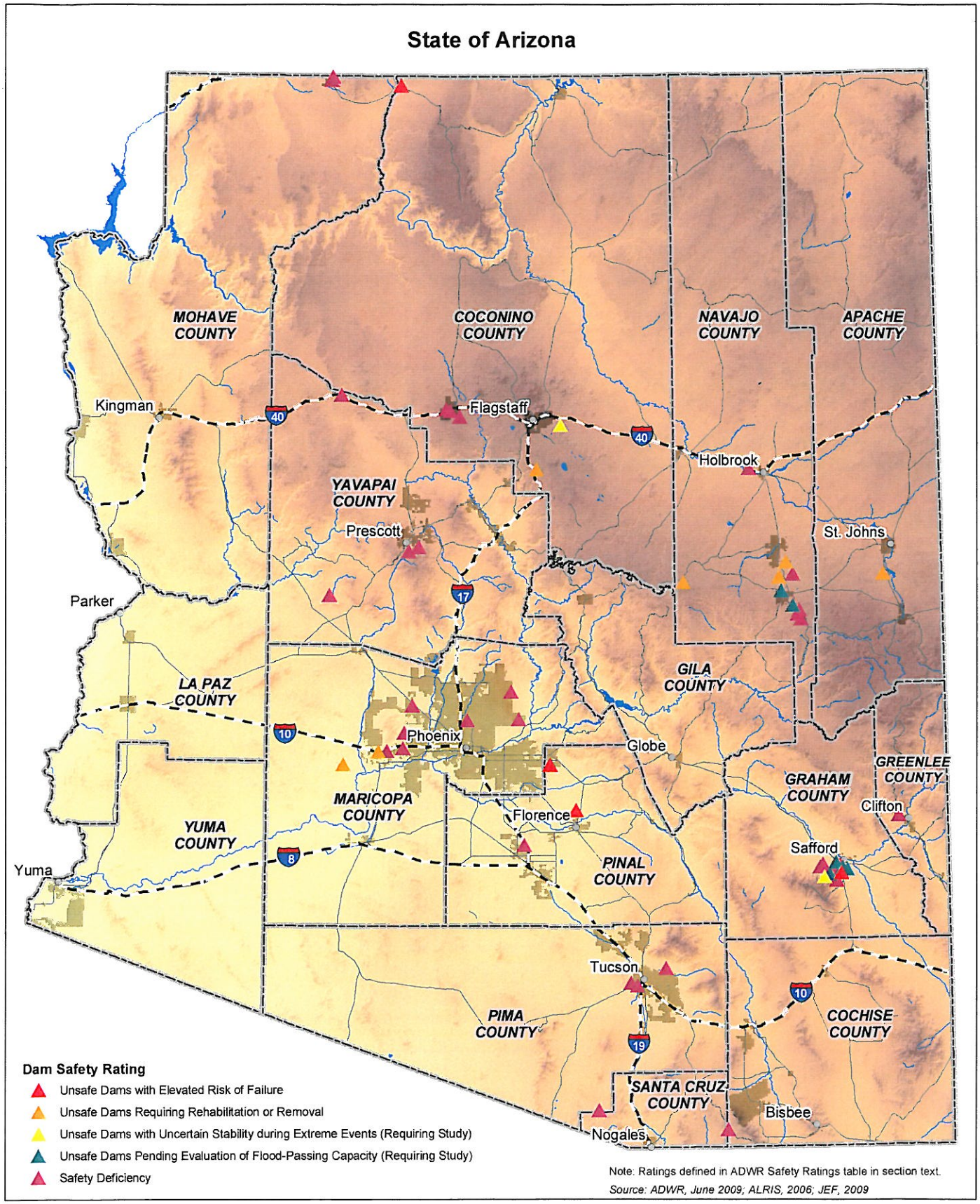
0 25 50 Miles

March 3, 2010

State of Arizona Multi-Hazard Mitigation Plan

Map 18
Federal and Jurisdictional Dams with Hazard Classifications
as of 2009

JE FULLER HAZARD MITIGATION & GEOSPATIAL LLC



Legend

- Major City
- interstate
- Highway
- Major Streams
- County
- Lakes
- Cities

0 25 50
Miles

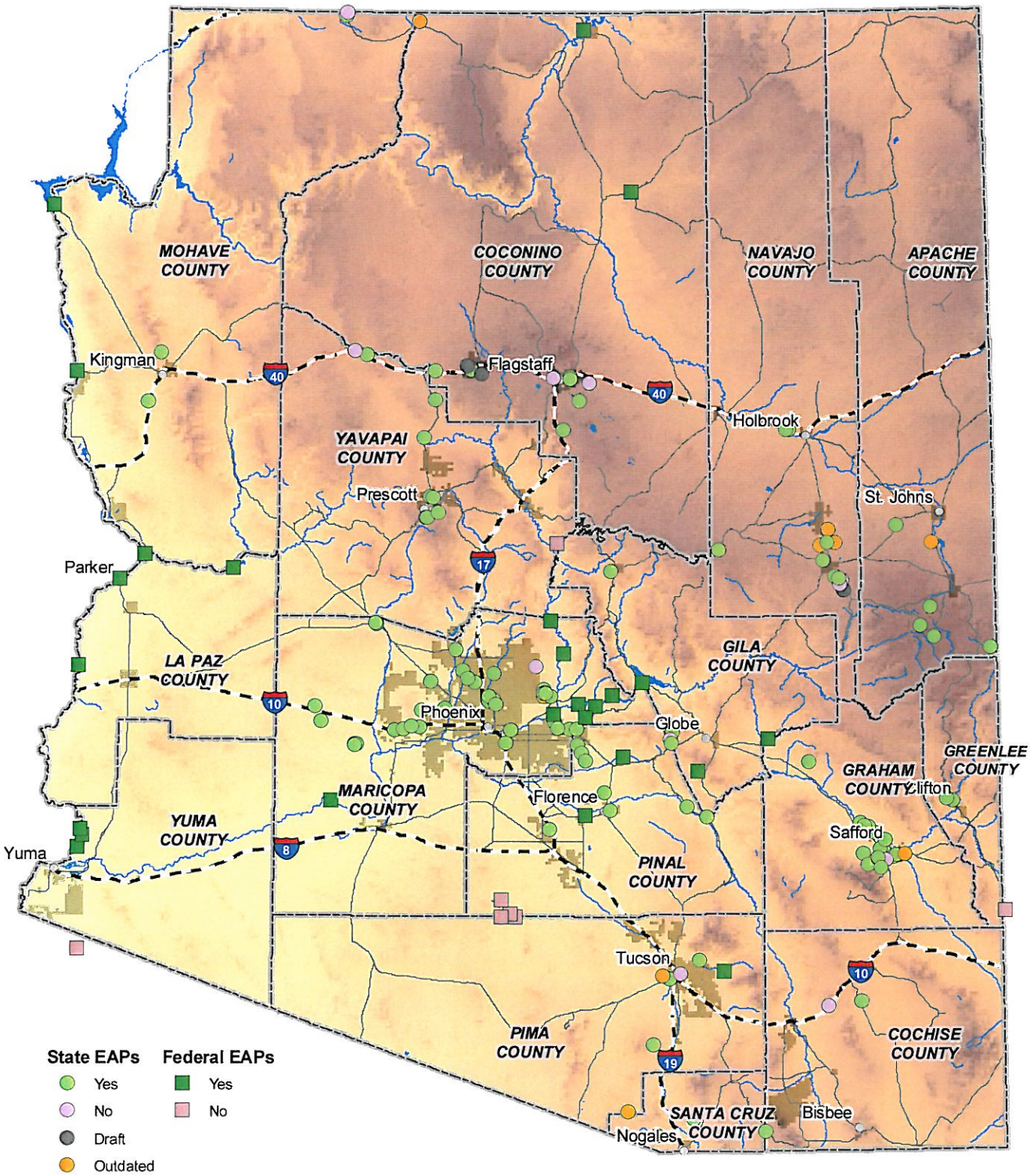
June 2009

State of Arizona Multi-Hazard Mitigation Plan

Map 19
State Regulated Dams with Identified Safety Deficiencies
as of 2009

JE FULLER HYDROLOGY & GEOMORPHOLOGY INC

State of Arizona



The data is derived from the Dam Safety Database.

Source: ADWR, June 2009; ALRIS, 2006; JEF, 2009

Legend

- Major City
- interstate
- Highway
- Major Streams
- County
- Lakes
- Cities

N

0 25 50
Miles

October 2009

State of Arizona Multi-Hazard Mitigation Plan

Map 20
Emergency Action Plans for Dams
as of 2009

JE FULLER HYDROLOGY & GEOMORPHOLOGY INC.